Improving Quality of Service in Cellular IP Domains

Balázs Rózsás, Sándor Imre
Department of Telecommunications,
Budapest University of Technology and Economics
Budapest, Hungary
{rozsas,imre}@hit.bme.hu

Abstract-- In today's networks there is a convergence to an integrated IP-based network. IETF's Mobile IP handles global macro-mobility in the IP based infocommunication networks. It is, however, not adapted to micro-mobility environment; in this local mobility management there are several proposals both for IPv4 and IPv6. These approaches use local entities to support mobility in a well-defined area (domain), and hide the movements inside the domain from Mobile IP. Future communication networks will transport not only voice calls but also other multimedia traffic. This type of data is sensible for packet delay, delay variation, packet loss, etc. To meet the requirements of users transmitting such data through the network we have to support better quality of service. In this paper we introduce an efficient solution for improving quality of service in Cellular IP micro-mobility domains. We also show simulation results for our new method.

I. INTRODUCTION

Future's cellular phones will transport everything (data traffic, voice calls, videoconferencing, signaling, etc.) in IP packets. Different types of the payload need different requirements in the network. The real-time multimedia transmissions (e.g. video conferencing) do not tolerate high delays or delay variations. The IP network should support quality of service provision in order to meet the subscribers' requirements.

The IETF Mobile IP [1] introduces a home network (home subnet) for each mobile host. In the home network there are several home agents and one of them is responsible for forwarding packets to a given mobile away from its home network. Mobiles have to register their care-of-address (a valid temporary IP address in the currently visited foreign network) at their home agent so it can forward mobile's packets to the foreign network. Mobiles inside their home network are accessible through their home address that is valid in the home network and is known by any correspondent hosts (communication partners of the mobile). Mobile IP protocol is considered to have limitations in its capability to handle large number of Mobile hosts moving fast between different radio cells. The handover frequency should typically not exceed once a second. However, Mobile IP is well suited for interconnecting disparate cellular networks effectively providing global mobility. Resulting from this some micro mobility approaches have been proposed.

These protocols [2, 3, 4, 5] handle mobility in a well-defined geographical area and hide the movements of the mobile host inside this area (or domain). We present our QoS method within the Cellular IP [3] protocol set. Micro-mobility protocols cooperate with the global macro-mobility protocol (the above described Mobile IP) for handling location management. Usually they use another (local, or regional) care-of-address, or some other addresses through which mobile is addressable. Obviously mobiles have to do some kind of registration also for micro-mobility protocols.

The basic architecture of a micro-mobility supporting global IP network can be seen in Figure 1. The subnets (both foreign and home subnet) and also correspondent hosts are connected via the global IP backbone. The care-of-addresses of the mobiles registered at the home agent change when a handover between subnets happens.

A typical micro-mobility domain consists of a border or gateway router, several routers and base stations. The gateway connects the domain to the backbone; base stations perform the communication with the mobiles through the radio interface. The routers are responsible for location management; they have to forward packets to its destination.

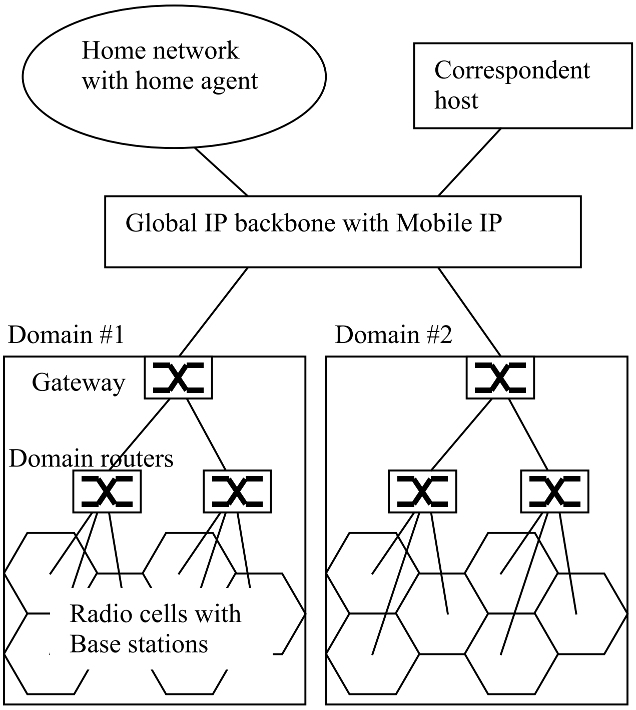

Figure 1. Architecture of a Mobile IP network with micro-mobility (Cellular IP) support.

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Most of these protocols above have their version for IPv4 and IPv6, the older and the newer version of the Internet Protocol. In this paper we concentrate on version 6 unless we emphasize version 4.

This paper is organized as follows: In Section II. and III. we present the Cellular IP micro-mobility architecture and the two basic architecture for supporting quality of service (Integrated and Differentiated services models). In Section IV. we introduce our new method for improving quality of service in Cellular IP domains. Finally our simulation environment and results are shown in Section V. and VI., respectively.

II. CELLULAR IP

Cellular IP (CIP) is an IETF proposal [3] for supporting micro-mobility in an IP network. A Cellular IP domain is a tree of CIP routers that forward packets and perform location management of the mobiles in the domain using two types of caches. A sample Cellular IP domain can be seen in Figure 1. The leaves of the tree are base stations (radio access points) that transmit packets to and receive them from mobiles via a link layer protocol. At the root of the tree there is a gateway router, which has similar functionality to other domain routers but has additional functions, like registration management, and acts as home agent of its domain.

The Cellular IP micro-mobility protocol is intended to provide local mobility and handover support. It can interwork with Mobile IP to provide wide area mobility support. Cellular IP is a proposal to the IETF made by researchers from Columbia University, New York and Ericsson in 1998 and 1999. Besides the Mobile IP protocol engine, Cellular IP mobile hosts have to run a special Cellular IP protocol engine that controls the mobility support of the network to a mobile host. The four fundamental design principles of the protocol are:

- Location information is stored in distributed databases,
- Location information referring to a mobile host is created and updated by regular IP datagrams originated by the said mobile host
- Location information is stored as soft state
- Location management for idle mobile hosts is separated from location management of hosts that are actively transmitting or receiving data.

Hosts connecting to the IP network via a wireless interface are likely to change their point of access frequently. A mechanism is required that ensures that packets addressed to moving hosts are successfully delivered with high probability. During a handover, packet losses may occur due to delayed propagation of new location information. These losses should be minimized in order to avoid a degradation of service quality as handover become more frequent. Cellular IP provides mobility and handover support for frequently moving hosts. It is intended to be used on a local level, for instance in a campus or metropolitan area network. Cellular IP can interwork with Mobile IP to support wide area mobility, that is, mobility between Cellular IP Networks.

A Cellular IP domain, see Figure 1., comprises a gateway router that connects the Cellular IP network to the Internet as well as several Cellular IP nodes that are responsible for the Cellular IP routing and mobile hosts which support the Cellular IP protocol. A mobile host is connected to a wireless access point (base station), to which it relays the packets it wants to transmit and from which it receives the packets destined for it. Each Cellular IP node has an uplink neighbour to which it relays the packets originating from the mobile hosts and one or more downlink neighbours to which it relays the packets destined for a mobile host. The gateway also has to play as a home agent for mobiles, whose home domain is this one, and which are away from this domain.

After power up a mobile host has to register to the Cellular IP network, which means that it has to set up a routing path from the gateway router to its current attachment point. This is done in a reverse manner by sending a route update message from the mobile host to the gateway router. The route update message is received by the base station and forwarded hop-by-hop following the uplink neighbours of each Cellular IP node towards the gateway router. Each Cellular IP node maintains a route cache in which it holds host based routing entries. Whenever a route update message passes a Cellular IP node, a routing entry for the related mobile host is written in the cache. The so-called host based entries map a mobile host's IP address to the interface from which the packet arrived at the node. When the route update message arrives at the gateway router, it is dropped after the gateway router added a routing entry to its route cache. After that, the chain of cached host based routing entries referring to a specific mobile host constitutes a reverse path for packets addressed for that mobile host. The routing entries in the Cellular IP nodes are soft state. This means, after a certain expiration time they are not valid any more. This is necessary since due to a link loss a mobile host might not be able to tear down its routing entries before leaving the network. In order not to lose its routing path, a mobile host has to refresh its routing entries periodically. In Cellular IP this is done by a regular data packet or by sending a route update message if the mobile host has no data to transmit.

Mobile hosts that are not currently transmitting or receiving data (idle state) but want to stay reachable have the opportunity to maintain paging cache entries. A mobile host with installed route cache entries is said to be in active state. Paging caches are not necessarily maintained on each Cellular IP node and have longer timeout values. On Cellular IP nodes, where both route and paging caches are maintained, packet forwarding in downlink direction is done in the same way for routing and paging with priority to the route cache entries. If a Cellular IP node, that does not maintain a paging cache, receives a downlink packet for a mobile host for which it has no routing entry in its route cache, it broadcasts the packet to all its downlink neighbours. By this mechanism, groups of several, usually adjacent base stations are built in which idle mobile hosts are searched when a packet has to be delivered to them. Those groups of base stations are called paging areas.

Cellular IP provides two handover mechanisms: A hard handover and a semi-soft handover mechanism. For a hard handover, the wireless interface of a mobile host changes from one base station to another at once. For the semi-soft handover the mobile host switches to the new base station, transmits a route update message with a flag indicating the semi-soft handover and returns immediately to the old base station in order to listen for packets destined to it. The route update message reconfigures the route caches on the way to the gateway router as usually, except for the route cache on the crossover node, where the new path branches off from the old path. In that node downlink packets are duplicated and sent along both paths until a new route update message.

III. QUALITY OF SERVICE

There are two major frameworks for providing quality of service: Integrated services model (IntServ) [7], and Differentiated services (DiffServ) [8] model. Other QoS issues, motivation, discussion about control and data path mechanisms can be found in [6].

Integrated services model handles every connection separately, which means that for every connection IntServ allocates a virtual path using Resource Reservation Protocol (RSVP) and guarantees the allocated bandwidth. With other word it can be called a per-flow based QoS framework, routers stores soft-state entries for each connections. Soft-state means that they must be refreshed periodically until the end of the connection, similar to the Cellular IP cache entries. The main drawback of this solution is that it is not scalable for big load, when the number of connections increases the number of necessary entries also will be always greater. The other shortcoming is that in a dynamic, mobile environment, where users change their point of attachment to the network, the reserved path must be reallocated that can result a great delay.

For signaling protocol of the IntServ architecture the Resource Reservation Protocol is used as we have mentioned earlier. The flow source first sends a PATH message to the receivers specifying the flow characteristics. Routers along the path store these requirements. The receiver replies with a RESV message, which will allocate the resources in reverse order while propagating backwards. If there is enough resource in the routers the flow is set up, resources are reserved for that connection, the communicating partners can start transmitting data packets.

DiffServ's main goal is scalability; it does not handle packets separately for each connection. In this framework packets are classified based on their traffic characteristics and these classes are handled in the same way. Diffserv needs differentiation at the network boundary (because there are relative a small number of flows, so this more complex function can be done there).

In IPv6 header there are reserved fields for classifying packets namely the 8-bit traffic class and the 20-bit flow label fields. In the specification of the IPv6 protocol [9] there is no definition given for the use of these fields. Flow label can be used by a source to label sequences of packets for which it requests special handling by IPv6 routers. Traffic classes can be used in both source host and routers to identify and distinguish between different classes and priorities of packets.

So we can say that providing QoS needs some kind of packet classification and differentiation in forwarding. In our solution we concentrate on the second one in the next section. We will give a method for ensure a possibility for packets with higher priority not to be dropped by a congestion but try to deliver them along an alternative path to the destination.

IV. IMPROVING QOS IN CIP DOMAINS

In this section we present our new method for improving quality of service support (i.e. decreasing packet loss and delays) in Cellular IP micro-mobility domains. This solution is based on extending the Cellular IP domain's topology that is basically a tree topology. Besides the branches of the tree we propose adding further branches to give a possibility for packets to be forwarded not along the default tree branch but along an alternative route. So we can split the traffic among these routes if there is not enough capacity somewhere in the domain. Sharing resources is essential for achieving better QoS.

These alternative routes are to be used when a normal (tree branch) route currently has not enough capacity and is not able to transmit the packet. Applying this method routers' capacity can be smaller for achieving the same QoS, and the traffic on an overloaded branch can be redirected to another branch, where there is more capacity available.

Of course the gateway router of the Cellular IP domain is a bottleneck (also from the viewpoint of reliability: failure in the gateway causes interruption of all connection to the global IP network (or any outer network the domain was attached to).

A. Packet forwarding along alternative routes

We have to distinguish two basic cases. Packet forwarding upwards (from a mobile host in the Cellular IP domain through the domain's gateway to any correspondent host) have to be handled different than forwarding downwards (from the gateway to a mobile in the domain). The reason is that routers of the domain handle these two directions in a different way. Although by IP telephony we can assume that the traffic amount approximately equals in the two directions between the communication partners but in the case of a multimedia, HTTP, FTP session the load is asymmetric. This is another reason why to distinguish the two directions.

In the upward direction a packet received by a router, which earlier has received advertisement about congestion from the routers above it in the tree, can be passed to another branch of the tree using an alternative route. The downward direction must be handled differently, a bit more complicated. A packet from uplink destined to a given mobile cannot be forwarded through another branch of a tree because there is no information about the location of the mobile host there. This can be solved by sending location updates also along the (possibly needed) alternative routes from the mobiles. Using Cellular IP this can be implemented by doubling route-update messages in the routers and sending to both the default and alternative route (upwards). If we maintain additional entries in routing caches of routers in the alternative route it will be possible to use this when there is a demand for an alternative way downwards. These entries do not play any role when there is no congestion downwards. Other way it does not differ from "normal" route-update entries in any route caches. It is important to maintain also this entry with the default route's entry because congestion can begin at any time and after that we have no tool to search a route. Except broadcasting, but this is not a proper method by congestion, because it largely increases the load, so decreases performance of the network.

This solution of handling downward congestion has a shortcoming: when the mobile host is inactive it has no route cache entries – so it does not have any downward alternative routes either. It means that this host cannot get any packets until the congestion ends. In this case we can use a broadcast message started at the alternative route of the router before the congestion. This event occurs more rarely than the congestion in general (there is an additional condition: inactivity of the mobile host). There is another way to "handle" this case: in a congested network the probability of connection interruption (of a real-time connection) or the packet loss is much greater than in a not overloaded network. So it can be a good solution not to allow this mobile to become active. We can extend with this condition the Call Admission Control (CAC) algorithm, which can deny the call at that time. After that we can simple drop the packet that caused this problem. Using alternative routes the CAC algorithm can allow more users below a router than without alternative routes because the traffic has an additional route.

Another solution is possible, but this requires an extended Cellular IP domain (which cannot be called a Cellular IP domain). The paging caches should store the IP addresses of the base stations mobiles are attached to (base stations must have an IP address). Inside the domain IP routing is needed. Assuming these conditions a packet from uplink that cannot be forwarded to the proper route because of congestion can be sent to the base station using an alternative way. Of course the IP routing must support more routes and not to try to send the same, congested direction.

So we handle the alternative routes in the two directions in a different manner. A packet from the mobile host will be routed to the alternative path when a router at the bottom of the tree cannot forward it to the default route. But this condition has effect only on this direction; packets from the gateway can reach the mobile on the default route if there is enough free capacity downwards. But independently from this an alternative route must be maintained because we cannot be sure when the route downwards will be congested. And if we did not have maintained it in the case of congestion we would not have any information about the location of the mobile host anywhere. Only the congested router knows its location, which cannot deal with our packet so that must be dropped. We can also store for a time instead of drop, but a real-time connection probably will not tolerate it and cannot do anything with a delayed packet.

B. Congestion and signaling

Congestion downwards can be present when the uplink neighbour of a router, which has greater capacity because it serves several downlink routers besides, wants to send more packets to this router than its capacity. It means that a lot of mobile hosts belong to this router. Upward congestion begins when several downlink neighbours of a router send too many packets upwards and the router cannot operate at that load.

Advertising the congestion towards the neighbours can be done using ICMP packets or IP packets containing information about the congestion (how much data can be transmitted to the sender router without packet loss). In the case of IPv6 this information can be also hold by an IPv6 extension header.

C. Inter-domain alternative routes

There is another question regarding the border of neighbour domains. How can we use capacity from the neighbour domain? We cannot simple pass the packets to a router in another domain because it will be forwarded to the default route i.e. the gateway router of the other domain. At the other gateway the mobile has no valid registration, furthermore there can be problems outside the domain when ingress filtering is used. The mobile host's care-of-address can be invalid by sending packet from the other domain. Intermediate Cellular IP routers (not gateway routers) can be used without any further things to do, but they have to know about the packets routed on an alternative path that they have to sent back to the original domain. Accordingly the routers must forward them towards the original gateway and not the router's default gateway. Route update messages contains the gateway router's IP address as the destination address, using this the router can store an entry for upward forwarded packets. This entry is independent from Cellular IP's route and paging cache, used only for forwarding packets from the alternative route. The gateway's IP address is necessary, it is not enough to know that a given link is an alternative route, because there can be more neighbour domains. Downwards there is no difference between intra-domain and inter-domain alternative routes, the router will simply forward the packet to the proper downlink interface if exist an entry in the routing cache. Here the two domains are simply overlapped through the alternative routes.

D. Discussion

The method we presented above is obviously closer to the differentiated services QoS architecture than the integrated services model. We do not handle every connection, we do not use RSVP or any resource allocation, we only route a group of packets to an alternative way towards their destination using the available resources in the other parts of the domain. Through this we can achieve better utilization of our devices (routers), serve more users, increasing the profit without any additional capacity.

It is worth using this algorithm when there is an asymmetry in the network load and additional unused resources are available in the other parts of the network. Inactive mobile hosts are not important because they become active before sending packets or after receiving the first packet. They do not generate any essential traffic anyway.

This solution is independent from further methods used above it outside the domain, it increases the utilization of the micro-mobility domain's resources, does not perform any packet classification. Of course it is possible to use the flow label or the traffic class field of the IPv6 header for classify packets. Adding priority to classes the higher priority classes could have scheduled first to the default route, and lower priority classes will be forwarded along the alternative path. Or there can be a priority limit, that below packets are not forwarded to the alternative path independent of the congestion on the default path (we leave more resources for higher priority classes from another sources). Packet classification can be done based on the demands of the user application: packet delay, delay variation, packet loss, etc. This solution would be a differentiated services architecture and ensures better QoS for higher priority classes than the basic method we introduced above.

Integrated services is better for end-to-end QoS provision, because it is unnecessary to guarantee hard conditions until the gateway if after that there is only a weaker QoS solution. If a packet will be lost later then it should be lost as soon as possible not to load the network unnecessary. Of course it is possible that inside a domain we have different traffic load than outside the domain, but get information about the conditions outside the domain needs additional resources and time. Sending packets to an alternative path where the load is lower it is expected that the average delay of packets will decrease.

V. SIMULATION ENVIRONMENT

Our simulation environment was prepared in OMNeT++ [10] that is an object oriented discrete event simulator based on C++. It was primarily designed to simulate computer networks, communication protocols, traffic modeling and other distributed systems. A model in OMNeT++ consists of hierarchically nested modules. Through their connections modules are able to pass messages to each other. The topology of modules is described in NED (NEtwork Description Language); operation of modules is to be implemented in C++. There are two principles available for the latter: the co-routine based mechanism (parallel "threads") and the handleMessage (function call when an event occurs for the module). OMNeT++ provides a powerful Tcl/Tk based graphical animation tool for viewing network simulation traces. It supports topology layout, packet level animation, and various data inspection tools.

We designed and implemented an IP mobility simulator in this simulation environment and investigated our new method. We created a sample network that contains two Cellular IP domains, a correspondent host and several mobile hosts. Our test domains consist of a gateway router that is responsible to handle the communication towards the Internet, five additional routers, six base stations (radio access points). These devices represent a micro-mobility domain; they are encapsulated in an OMNeT++ module. The micro-mobility domains are contained by a module called AS, which can be used later for modeling a provider's network or AAA (Authentication, Authorization, Accounting) domains. Inside this domain there can be also a wired host beside the micro-mobility domains. These AS-es are interconnected via a backbone network, which routes packets based on their IP address prefix that identifies the destination AS. There can exist an AS without any wireless access part. We use such an AS for modeling a correspondent host for the mobile hosts. Between the mobiles and base stations we use an Air object modeling the radio channel and handling the movement of mobiles. The architecture of our simulation can be seen in Figure 2., which was taken from OMNeT++ Tcl/Tk graphical user interface. The main window can be seen in the upper right corner with the backbone, AS-es, Air, and mobile hosts. At left there is an AS with two micro-mobility domains and a correspondent host. The architecture of the test domain is visualized at the bottom of the figure. We have a tree of router with three levels. We have six base stations, total 12. They are placed in a hexagonal manner in 3 rows and 4 columns.

In the simulation, currently the objects mentioned above are implemented (the operation of the objects is in accordance with the relevant IETF proposals):

Mobile host: This object models the end user's equipment attaching him to the network. It sends and receives IP packets to and from the Internet. It moves towards a random

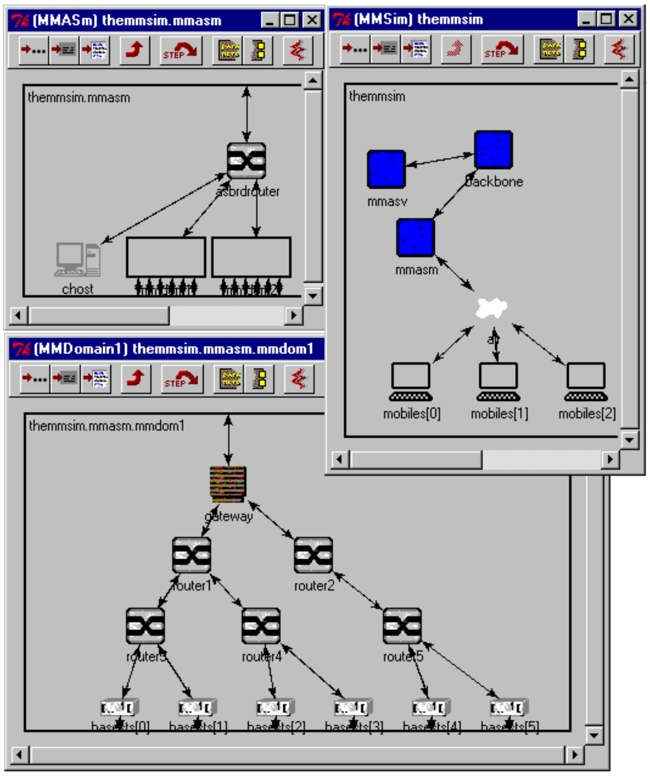

Figure 2. The architecture of the test network

target position with a random speed. After reaching the target it chooses a new target and velocity and continues its walk.

Air interface: It forwards packets between the base stations and mobile hosts. It is responsible for the limited radius of the covered area of an antenna of a terminal or base station.

Base station: Simply forwards the packets between the first router and the air interface object.

Domain Routers: They forward packets uplink and downlink. They maintain a routing table that contains the IP addresses of the mobiles that can be accessed through a downlink interface of the router. A packet to be delivered to a mobile under the router is forwarded towards the interface that is addressed by the entry related to the destined mobile.

Gateway router: This object extends the simple router forwarding function with registration and home agent functions. A mobile arriving in a new micro-mobility domain has to register itself by the gateway router. The gateway router provides interoperability between the micro-mobility domain and the wired Internet.

AS: An object that contains several micro-mobility domains and a wired host.

Backbone router: It models the whole Internet, interconnects/links the networks to each other.

Correspondent host: It communicates all the mobile hosts, sends and receives packets.

We have implemented the following messages in the simulator:

Beacon signal: The base stations send this signal periodically. The mobiles, which are close enough to a base station, can receive this signal. The mobiles can decide which base station is the nearest one. This signal includes the identifier of the micro-mobility domain, the paging area and the base station. Hence the mobile host can sense the change of these objects (inter-domain/intra-domain handovers arriving in another paging area).

Paging update: A mobile host sends this signal if it is in idle state and changes its paging area inside the domain. It also must be sent if a certain time elapsed.

Route update: A mobile host sends this signal if it is in active state and changes its base station inside the domain. It also must be sent if a certain time elapsed.

Binding update: Sent by the mobile host to the correspondent host or the home agent when the mobile changes its care-of-address or there is a timeout for the binding list entry

Binding acknowledgement: Reply for binding update.

Regular IP datagram: This packet is used to transmit payload over the network.

VI. RESULTS

We used the previously described simulator to test and validate our proposal. The duration of the simulation was 100 time units of the OMNeT++ environment. The users were moving according to the random walk mobility model and independently from one another inside the simulation area. The base stations covered not the whole area, so mobiles can lost their connection to the network. At the beginning of the simulation, the users were identically distributed over this area. Every user moved from a random position to another randomly chosen position. The traffic of the hosts was modeled as a random ON-OFF source. If the mobile is ON it generates IP packets addressed to the correspondent host located outside the micro-mobility domain. We also changed the topology of our domain. We added our alternative routes between the first and second level of the router-tree (counted from 0) as can be seen in Figure 3. In this figure the first domain is shown but the second one has the same structure. The inter-domain alternative paths are connected to each other.

We investigated the number of lost packets and packet delays in the network. The main reason of packet loss is the congestion at routers in the micro-mobility domains. There are also further reasons that can cause a packet loss but we have chosen the parameters of protocols used in the simulation to minimize the probability of these events. We set the Mobile IP's binding cache, and Cellular IP's route and paging cache timeout to a relative great value, and mobiles had to refresh them relatively often. So the probability of the event that the home agent or a router has no entry for the given mobile host was small. (When no valid entry found in a router or home agent it has to drop the packet because it does not know any route to the destination, so the packet is lost.) After that we assumed that the packets are lost because of congestion in routers of domains. We changed the traffic load (i.e. the parameter of an exponential distribution) of the correspondent host and the mobile hosts. This load parameter is used for calculate the time interval between the packets following each other during a connection from the same source.

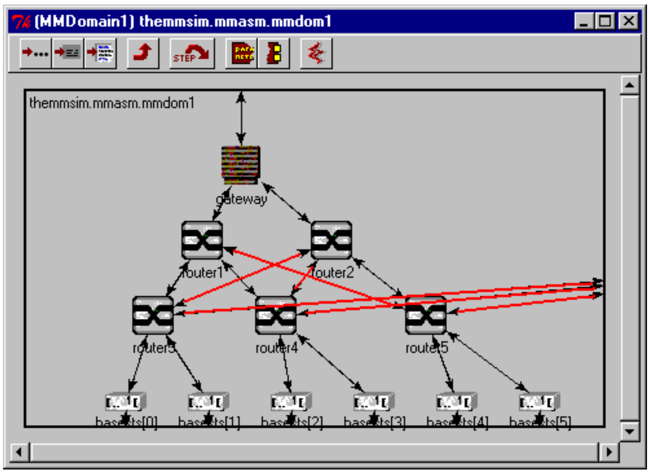

Figure 3. The domain with alternative routes inside and between domains.

OMNeT++ supports different distributions; we used an exponential one to calculate these intervals. The correspondent and mobile hosts use this algorithm to generate packets. The smaller parameter value means higher load (packets are sent more frequently, time intervals are short between them); the expected value of the distribution is the reciprocal of this load parameter. This traffic model is currently very simple and needs further improvements in the future.

In the first diagram we show the number of lost packets (as percentage of total number of packets) in the function of the traffic load (the parameter of the exponential distribution described above). The values of the load cover a range; within there is an overloaded case and also a nearly empty network (see Figure 4).

We can say that using alternative paths when there is congestion in the network we can improve the performance of the micro-mobility domain from the viewpoint of packet loss. The difference is more significant in an overloaded network (small values of the x-axis), here the ratio was with up to 10% better. By a low load the difference is not significant. In that case there is no need for alternative paths with these router capacities. But it means that if we had such few users we can decrease the capacities of routers - we can apply smaller domain routers if possible. In Figure 4. we show separately the upward and downward cases. Along the x-axis the odd elements represents the packet loss upwards, the even ones the downward direction. There is no important difference between the two directions, because the traffic load from the correspondent host and from mobile host has the same properties and the algorithm handles these two cases in the same manner - uses alternative paths.

For multimedia connections another important parameter is the delay of the packets. We measured that as the difference of the packet's arrival and sending time. The delay of lost packets was not considered here, because no valid delay can be assigned to them. In Figure 5. the packet delays are shown with the same load parameters as the previous one.

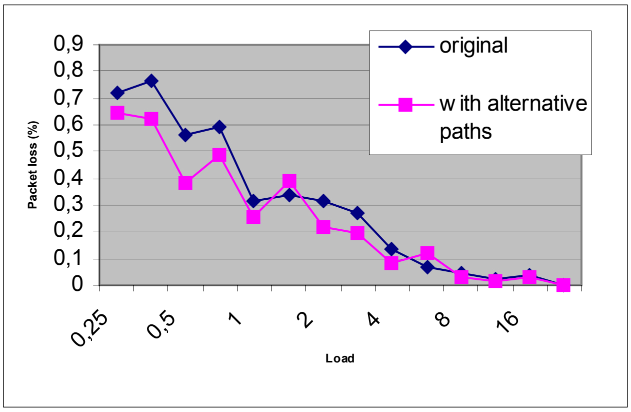

Figure 4. The ratio of lost packets to the total number of packets.

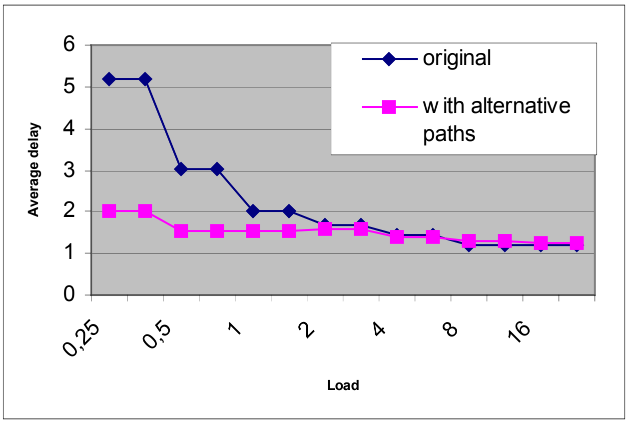

Figure 5. Average packet delays.

The difference is more significant here than in the previous case. At high load (smaller parameter values) the average delay can be better with more than 50% of the original one (i.e. without alternative paths). The reason is that the delay added by the routers depends on the load of the router. In our model a router just before being overloaded added one-second delay to the packets. Of course an overloaded router has dropped all packets. At low loads also here there is no significant difference, the added delay is the ratio of the load and capacity.

VII. CONCLUSION AND FUTURE WORK

In this paper we presented a new method for improving quality of service in Cellular IP micro-mobility domains. It is possible to apply the method in any tree topology micro-mobility solutions. Adding alternative paths can be implemented also in hierarchical solutions or other tree based micro-mobility proposals. Our simulation results were also presented. We could decrease the probability of packet loss and the delay in the micro-mobility domain. Both of these parameters are very important for real-time, multimedia traffic.

In the future we plan to improve our simulation, implement more traffic and mobility models, extending it with further micro-mobility protocols. As we mentioned earlier this traffic model needs much improvement to model the real traffic conditions more accurately than the currently applied one. The characteristics of the traffic must depend on the type of the traffic we simulate. E.g. a real-time multimedia connection generates a different kind of traffic than a voice call or the file downloading. The random walk movement modeling must be also refined. We want to give analytical results and compare them to the results from the simulation.

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